Development and Deployment of an Extreme Turbulence (ET) Probe for Hurricane and High-Wind Research

Richard M. Eckman
NOAA Air Resources Laboratory, Field Research Division
1750 Foote Drive
Idaho Falls, ID 83402
phone: (208) 526-2740 fax: (208) 526-2549 email: richard.eckman@noaa.gov

Timothy L. Crawford (deceased)
NOAA Air Resources Laboratory, Field Research Division
1750 Foote Drive
Idaho Falls, ID 83402

Ronald J. Dobosy
NOAA Air Resources Laboratory, Atmospheric Turbulence and Diffusion Division
456 South Illinois Ave.
Oak Ridge, TN
phone: (865) 576-1250 fax: (865) 576-1327 email: dobosy@atdd.noaa.gov

Randall C. Johnson
NOAA Air Resources Laboratory, Field Research Division
1750 Foote Drive
Idaho Falls, ID 83402
phone: (208) 526-2129 fax: (208) 526-2549 email: randy.johnson@noaa.gov

Gennaro H. Crescenti
NOAA Air Resources Laboratory, Field Research Division
1750 Foote Drive
Idaho Falls, ID 83402
phone: (208) 526-2328 fax: (208) 526-2549 email: jerry.crescenti@noaa.gov

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LONG-TERM GOALS

Turbulent exchanges of heat and momentum between the atmosphere and the underlying surface are a primary driving factor in the intensification and decline of tropical cyclones. Few in-situ observations of turbulence and surface fluxes have been made in the extreme environment associated with tropical cyclones. Standard turbulence instruments are not designed to function in strong winds exceeding about 20 m s^{-1}, nor are they designed to function in heavy rain. An Extreme Turbulence (ET) probe is being developed to measure near-surface winds, turbulence, and fluxes in the high winds and precipitation rates encountered in tropical cyclones. This probe also has potential applications to other atmospheric phenomena that produce high winds.

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14. ABSTRACT
Turbulent exchanges of heat and momentum between the atmosphere and the underlying surface are a primary driving factor in the intensification and decline of tropical cyclones. Few in-situ observations of turbulence and surface fluxes have been made in the extreme environment associated with tropical cyclones. Standard turbulence instruments are not designed to function in strong winds exceeding about 20 m s-1, nor are they designed to function in heavy rain. An Extreme Turbulence (ET) probe is being developed to measure near-surface winds, turbulence, and fluxes in the high winds and precipitation rates encountered in tropical cyclones. This probe also has potential applications to other atmospheric phenomena that produce high winds.

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OBJECTIVES

The objectives of this project are:

1. To design, build, and test an ET probe suitable for deployment in the extreme conditions found within tropical cyclones or other storms associated with hurricane-force winds.

2. To deploy three to five ET probes in the path of a landfalling tropical cyclone to observe changes in winds, turbulence and surface fluxes as the storm moves inland.

3. To collaborate with other scientists in deploying ET probes in high-wind conditions, particularly in the maritime boundary layer.

These objectives fit into the overall goals of both the ONR Coupled Boundary Layers Air-Sea Transfer (CBLAST) initiative and the Hurricane at Landfall initiative sponsored by the U. S. Weather Research Program.

APPROACH

The project is developing a relatively low-cost, robust probe that can measure turbulent fluctuations in the high winds (> 30 m s^{-1}), heavy rain, and spray associated with strong tropical cyclones. The NOAA Air Resources Laboratory (ARL) has for many years used pressure-sphere anemometers (Brown et al. 1983; Crawford and Dobosy 1992) to measure turbulence quantities from fixed-wing aircraft. These devices use pressure sensors connected to an array of holes on a spherical surface. The observed pressure distribution near the flow stagnation point is used to compute the magnitude and direction of the incident airflow. In aircraft applications, these anemometers are routinely operated at airspeeds of 50-60 m s^{-1}, which corresponds to a category 3 hurricane on the Saffir-Simpson scale. An anemometer of this design will therefore have no difficulty operating in hurricane-force winds as long as the sphere is not damaged by airborne debris. In fact, they become somewhat easier to operate in higher winds, since the pressure fluctuations are larger in magnitude and thus easier to detect.

On an aircraft probe, only a partial sphere with a few pressure ports pointing forward is required. A ground-based probe needs to be omnidirectional, so a full sphere with ports evenly spaced around the equator is required. Figures 1A and 1B show the basic concepts behind the Extreme Turbulence (ET) probe under development at ARL. The 43 cm diameter spherical shell is made from fiberglass-epoxy composite. Ten pressure ports are located on the sphere's equator at 36° intervals. Two other sets of ports are located at "latitudes" of 18º above and below the equator; these are aligned vertically with the equatorial ports. The 30 ports are connected to 20 differential pressure sensors and 6 absolute pressure sensors. Additionally, two temperature sensors are located in a small housing (not shown) on top of the sphere.

Figure 1C shows conceptually how the ET sphere is intended to operate. The raw pressure and temperature data are first digitized at 50 Hz. The processing software on a co-located notebook computer first attempts to remove data spikes associated with rain. It then uses the pressure data to search for the location of the wind stagnation point on the sphere. Data from the pressure sensors closest to the stagnation point are used to compute a 50 Hz time series of the ambient wind vector. Next, the mean wind, turbulence statistics, and fluxes are obtained from the wind and temperature time series. Processed data are transmitted back to a remote location out of harm's way using a satellite telephone or other transmission technology.

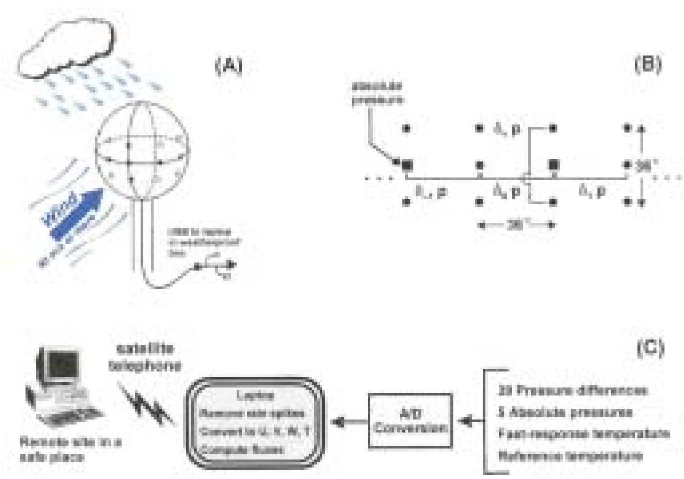

Figure 1. Basic concepts of ET probe. (A) shows the general design features, (B) shows the pressure-port spacing, and (C) shows the data acquisition.

Once several prototypes of the ET probe are completed and tested, they will be deployed near the coast in the path of a landfalling tropical cyclone. These deployments will be in collaboration with other scientific teams, as coordinated through the Hurricane Research Division of the NOAA Atlantic Oceanographic and Meteorological Laboratory.

WORK COMPLETED

The ET probe project suffered a major setback when Dr. Timothy Crawford, the original principal investigator, died unexpectedly in early August 2002. However, Dr. Crawford had already passed some of the oversight responsibilities of the project to Dr. Richard M. Eckman a couple of months prior to his death. The Air Resources Laboratory retains the expertise to develop and deploy the ET probes in spite of this setback.

In the early part of Fiscal Year 2002, modifications were made to the ET circuit boards and the internal plumbing of the pressure sensors. These changes were the result of issues that arose during field testing of the original prototype ET probe. Four complete ET probes have now been built based on the modified design. Three are intended for deployment in a landfalling tropical cyclone, and the fourth is to be used for further testing and development. The original prototype included an air pump to backflush the pressure ports and remove water, but this backflushing was left off the new probes due to problems noted below in the Results section.

Many improvements were made to the functionality and stability of the ET probe software during the year. The software, which uses an object-oriented design written in C++, was still in a beta development stage at the end of last fiscal year. It could record the raw 32-channel data stream and locate the flow stagnation point on the sphere, but it was not complete or stable enough for deployment in a tropical cyclone. Field tests of the probes both at the ARL Atmospheric Turbulence and Diffusion Division (ATDD) in Oak Ridge, TN and the Field Research Division (FRD) in Idaho Falls, ID led to many of the software improvements. The new software also takes advantage of process multi-threading, which allows the data collection and data processing to run as separate process threads on the computer. The original ET probe proposal included a capability to transmit the data to a remote location using a satellite telephone. This capability has been postponed to later years due to the project's reduced funding level compared to the original proposal.

In the spring of 2002, work started on developing an ET probe deployment kit for use in tropical cyclones. Prior development had focused on the instrument itself, but task 2 in the Objectives requires the development of towers and enclosures that can withstand hurricane conditions. Most of the development of the deployment kits took place at ATDD. Three complete ET probe deployment kits were ready in early September 2002. ARL was then ready to attempt a deployment of three ET probes in a tropical cyclone. To reduce costs and increase flexibility, the deployment was based out of ATDD, with Mr. David Auble, who developed the deployment kits, being in charge of the effort. At the time of this writing, the ET probes were heading towards the Gulf of Mexico Coast for possible deployment in Hurricane Isidore.

RESULTS

Experience with the first ET probe prototype lead to several improvements in the internal circuit boards and changes in the plumbing of the pressure sensors. Four copies of the improved design have been completed. Testing of the probes on moving vehicles indicates that the probes are providing reasonable time series of the incident airflow. It was also discovered that the backflushing of the pressure ports on the ET prototype caused problems with the pressure data, due to cross-contamination of the pressure channels and spurious pressure signals introduced by the air pump used for the flushing. The new ET probes therefore do not currently have port backflushing; this will be added in the future once a workable backflushing system is developed.

An investigation of the theory behind the ET probe's operation indicates it may be possible to reduce the total number of absolute pressure sensors from 6 to 2. This would further simplify the design and reduce unit costs. The 6 absolute sensors are used in approximating the location of the flow stagnation point. They are 72° apart along the equator, except at the seam between the two halves of the fiberglass sphere, where they are just 36° apart. In theory, the absolute pressure at any equatorial port can be obtained by combining the output of just one absolute sensor with the outputs of the differential pressure sensors that span the probe's equator. This means the probe may be able to operate with 1 absolute and 20 differential pressure sensors. However, for redundancy and to keep the two halves of the ET sphere identical, the alternate design would likely use 2 absolute sensors. This alternate design needs further testing before it is implemented, because additive noise in the differential pressure sensors may make it less desirable than the current design.

A hurricane deployment kit has now been developed for the ET probes. The major components are shown in Fig. 2. The ET sphere sits atop an aluminum tripod at about 3 m AGL. A notebook computer, deep-cycle battery, and other electronics are housed in the igloo-shaped, watertight enclosure. The tower and enclosure are structurally strong yet do not present a large cross section to the wind. They can be set up by a single person in under 30 minutes.

IMPACT/APPLICATION

The successful development of the ET probe will fulfill a need for turbulence and air-sea interaction data under high wind conditions. Standard turbulence instruments do not meet this need. The lack of air-surface exchange data in high winds is an important source of uncertainty in tropical cyclone modeling. ET probes have potential applications to other atmospheric phenomena involving high winds, including strong extratropical cyclones.

Figure 2. A photograph showing the ET sphere on a 3 m tower and the igloo-shaped watertight enclosure for the electronics.

TRANSITIONS

Other groups have expressed an interest in the ET probes once they are developed. Woods Hole Oceanographic Institution is interested in placing a probe at the Martha's Vineyard Coastal Observatory to study coastal storms. Likewise, Dr. Larry Mahrt at Oregon State University is interested in using them along the Pacific Coast.

RELATED PROJECTS

The Air Resources Laboratory has two other CBLAST projects that involve anemometer technology similar to the ET probes. The CBLAST-Hurricane project (http://www.noaa.inel.gov/projects/cblast-hurricane/) is installing a pressure-sphere anemometer on one of the NOAA WP-3D hurricane-hunter aircraft. This system is undergoing initial testing during the 2002 hurricane season. The CBLAST light-wind project (http://www.noaa.inel.gov/projects/cblast/) was using the NOAA Long-EZ aircraft with a pressure sphere to study maritime boundary-layer structure in weak winds, but this project was interrupted by the death of Dr. Timothy Crawford and the loss of the Long-EZ. Both ONR and NOAA are also supporting other groups deploying various ground-based sensors in tropical cyclones.

REFERENCES

Brown, E. N., C. A. Friehe, and D. H. Lenschow, 1983: The use of pressure fluctuations on the nose of an aircraft for measuring air motion. *J. Climate Appl. Meteor.*, **22**, 171-180.

Crawford, T.L. and R. J. Dobosy, 1992: A sensitive fast-response probe to measure turbulence and heat flux from any airplane. *Bound.-Layer Meteor.*, **59**, 2257-278.